Evaluation of Intumescent Coatings for Shipboard Fire Protection

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ABSTRACT: In response to several claims from Manufacturers that intumescent coatings could be used in place of fire insulation and provide equal protection to shipboard structures during a fire, U.S. Navy conducted an extensive investigation of several fire protective coatings for use aboard ship. These fire protective coatings included water and solvent based coatings, insulative coatings, and foams. The objective of this program was to identify passive fire protection (PFP) coatings for shipboard interior applications capable of meeting U.S. Navy (USN) fire resistance requirements (DRAFT MIL-PRF-XX 381) of 30 min rating with backside average temperature rise less than 139°C using UL-1709 fire curve (post flashover fire). This evaluation consisted of small scale fire, adhesion, and impact tests; intermediate scale room corner fire tests, and full scale fire tests conducted aboard ex-USS SHADWELL. The test results with steel substrate show that all candidate coatings failed to meet minimum U.S. Navy fire resistance criteria when used as stand-alone coatings. Furthermore, many coatings demonstrated poor adhesion, and fell off from the substrate during the fire test. These data have led the Navy to conclude that intumescent coatings tested in this study are not sufficient to protect shipboard spaces during a fire and are not equivalent when used alone as direct replacement for batt or blanket type fibrous fire insulation (mineral wool,

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StructoGard®) installed aboard U.S. Navy ships. However, U.S. Navy small-scale fire tests have also demonstrated that some of the intumescent coatings, when applied over substrates such as Glass Reinforced Plastic (GRP), did reduce flame spread and smoke generation.

KEY WORDS: Author please supply Keywords ???

INTRODUCTION

ONE OF THE most critical issues facing U.S. Naval shipbuilding is that of fire protection. Passive fire protection systems are used aboard Navy ships to contain fire and prevent fire spread to adjacent and overhead compartments. Passive fire protection systems, now covered under DRAFT MIL-PRF-XX 381 [1], should be capable of withstanding a fire resistance test using UL-1709 [2] fire curve which simulates a post flashover fire, for a 30 min minimum time while holding the backside average temperature rise of the substrate to a maximum of 139°C. The passive fire protection system shall be capable of withstanding shipboard environment, including the conditions of humidity, heat and cold, exposure to light, vibration, and shock as specified. Two such products which are approved by the US Navy for fire zone insulation are StructoGard® and Fire Safe®. StructoGard (SG) is a needled insulation blanket of proprietary composition (soluble amorphous fiber) manufactured by Thermal Ceramics Corp., and Fire Safe is a polyimide foam and amorphous wool insulation hybrid product.

There is an ever growing need to develop material systems that are lighter weight, more durable, and lower in cost. Advanced fire protection material systems include intumescent coatings. Intumescent coatings are based on their ability to swell or expand (intumesce) to produce char or foam which insulates and protects the substrate underneath from direct exposure to fire. These materials may be water or solvent based. Water based intumescent materials are nontoxic and environmentally benign which is vital to remain consistent with normal shipyard construction processes. Some shipbuilding contractors have also proposed combinations of currently used fire insulation with intumescent coatings to reduce the thickness, and thus reduce the weight of the passive fire protection systems.

Previous work by the US Navy included the study of intumescent coatings by Naval Research Laboratory (NRL) and Naval Surface Warfare Center, Carderock Division (NSWCCD). The objective of the NRL [3] study was to identify a fire protective coating that would adequately protect the antisweat hull insulation (PVC nitrile rubber) in the submarine interiors. This study selected coating G (an intumescent type). The objective of the NSWCCD [4] study was to identify suitable fire protective coating candidates to protect glass reinforced vinyl ester GRP structures. Other noteworthy studies of intumescent coatings include ''Innovative Fire Resistant Coatings for Use on Composite Products Aboard U.S. Commercial Ships''[5], MARITECH Project DTMA91-95-H-00091, March 2001 [6], and PMS 400 GRP Forward Director Room on DDG51 class surface ships [7]. When Northrop Grumman was required to protect their innovative topside composite demonstration module [7], an epoxy-based intumescent coating (Chartek) applied at a thickness of over 0.5 in. (1.27 cm) was used. This passive fire protection system did provide excellent passive fire protection during full-scale tests. However, when this material was tested in accordance with ISO 9705 [8] full scale room corner fire test, smoke production exceeded allowable limits. Epoxy-based intumescent coating suppliers do not recommend using their products for interior spaces for this reason.

In FY 01, the U.S. Navy initiated a new study of intumescent coatings to determine whether such Passive Fire Protection (PFP) coatings:

- Can be used as a replacement for fire insulation in shipboard interior applications;
- Can be used as an adjunct to fire insulation;
- Can be used to prevent flashover;
- Can withstand the wear and tear of shipboard environment and rigors of deployment without degradation from cleaning and top coating.

The objective of this new study was to identify passive fire protection (PFP) coatings for shipboard *interior* applications capable of meeting USN fire resistance requirements of 30 min rating with backside average temperature rise less than 139°C using the UL-1709 fire curve which simulates a post flashover fire. In addition to meeting fire performance requirements, PFP coatings were required to meet durability (adhesion, impact), environmental (washability, humidity, fluid and chemical resistance), and health (off-gassing, fibers) requirements.

EXPERIMENTAL

This study was carried out in following stages:

1. Solicit Passive Fire Protection (PFP) coating candidates capable of meeting USN passive fire protection goals from the open market (Commerce Business Daily announcement);

2. Develop screening tests pass/fail criteria for candidate coatings on the basis of small scale fire tests and other relevant physical properties;
3. Perform the small scale physical and fire tests on all candidate coatings on steel substrate at manufacturer's recommended coating thickness and down select coatings;
4. Perform the small scale tests on combinations of StructoGard and selected intumescent coating to reduce thickness (and weight) of StructoGard;
5. Perform the small scale physical and fire tests on down selected coating candidates with GRP substrates;
6. Perform room-corner fire tests on selected coatings; and
7. Perform full scale fire tests in ex-USS Shadwell (U.S. Navy Research Ship) with selected coatings on steel substrate.

Selection of Coating Candidates

This program started with an announcement in Commerce Business Daily (CBD), published November 2000, soliciting potential PFP coating candidates for evaluation. The list of candidates also included candidate materials recommended by other independent researchers from University, industry, and published literature. Selection of candidates for evaluation was based on the merits of their performance as reviewed from Material Safety Data Sheets (MSDS), relevant product literature from the manufacturer, surface preparation, coating application procedures and safety requirements such as solvents, ingredients, volatile organic content, etc.

A total of 19 coatings were selected for evaluation. The coating candidates, identified only with letter designations, are listed in Table 1. For control and comparison purposes, currently used Navy paint systems were also included in this task. These paints included: Coating G (fire protective coating for antisweat PVC nitrile rubber hull insulation); Coating H, MIL-PRF-46081 [9], Coating Compound, Thermal Insulating, Intumescent; and Coating Y, topcoat, DOD-E-24607 [10], Enamel, Interior, Nonflaming (dry), Chlorinated Alkyd Resin, Semigloss. Coating Y is a general use paint for interior ship bulkhead and overhead applications.

All coatings were applied with manufacturer's recommended primer. Where the supplier did not have a recommendation, Navy standard F-150 primer [11] was used. All coatings were evaluated at the manufacturer's recommended thickness. Some coatings were applied at multiple thicknesses.

Three different material substrates were chosen to evaluate the candidate coatings. These included 0.25″ (6.35 mm) thick mild steel,

Table 1. Selection of coatings for small scale testing.

Coating ID	Base	Generic Coating	Primer System	DFT Mils (mm)	Areal Density lbs/ft^2 (kg/m^2)	Comments
A	Water	Vinyl acetate	F150	50 (1.27)	0.36 (1.76)	
E	Water	Acrylic latex	Primer 490	55 (1.40)	0.37 (1.81)	
F	Solvent	Chlorinated rubber	Primer 490	200 (5.08)	1.05 (5.13)	
G50*	Solvent	Alkyd	634 Primer	50 (1.27)	0.41 (2.0)	Control
G10*	Solvent	Alkyd	634 Primer	10 (0.25)	0.082 (0.40)	Control
H50*	Solvent	Polyamide epoxy	F 150	50 (1.27)	0.36 (1.76)	Control
H10*	Solvent	Polyamide epoxy	F 150	10 (0.25)	0.071 (0.35)	Control
I30*	Water	Latex	F 150	30 (0.76)	NA	
I50*	Water	Latex	F 150	50 (1.27)	0.37 (1.81)	
J	100% solids	Epoxy	251	195 (4.95)	1.08 (5.27)	
K	100% solids	Epoxy	F 150	50 (1.27)	0.31 (1.51)	
L	Water	Latex	F 150	50 (1.27)	0.29 (1.42)	
N	100% solids	Epoxy	Proprietary	50 (1.27)	0.35 (1.71)	
O	Water	Acrylic	Proprietary	50 (1.27)	0.38 (1.86)	
P	100% solids	2 part silicone	F 150	1000 (25.4)	1.63 (7.96)	
Q	Water	Acrylic	F 150	62.5 (1.59)	0.27 (1.32)	
Q2	Solvent	Vinyl toluene butadiene	F 150	62.5 (1.59)	0.50 (2.44)	
R	Water	Silicone	F 150	1000 (25.4)	1.96 (9.57)	
Y	Solvent	Chlorinated alkyd	F 150	10 (0.25)	NA	Control
SG	HT glass fibers			1.25 in (31.8 mm)	1.0 (4.88)	Control

* = Number next to coating ID represents the coating thickness in mils; NA = Not Available

1.25″ (31.75 mm) thick StructoGard, and 3.5″ (88.9 mm) thick GRP sandwich composite.

Acceptance Criteria for Small Scale Screening Tests

All selected candidate coatings were subjected to a series of small scale screening tests using the steel substrate. The screening acceptance criteria were developed through a review of applicable Navy standards relevant to coatings and passive fire protection. Draft MIL-PRF-XX 381[1] was used as a guide to set acceptance criteria for areal density, flame spread, and fire resistance. MIL-STD-2031 [12] was used as a guide to set acceptance criteria for smoke generation, heat release rate, and time to ignition. Although MIL-STD-2031 was developed for composites, this is the only applicable Navy standard for Cone Calorimeter heat release rate data. In some cases, the demonstration of equivalent performance to coatings that are currently in use by the Navy was utilized as a guide to set acceptance criteria for physical properties. Coating G, which is a NAVSEA approved coating for submarine application, was used as a guide to set acceptance criteria for adhesion. Coating H, which is currently on the Qualified Products List (QPL) for MIL-PRF-46081 [9] (Coating Compound, Thermal Insulating, Intumescent) was used as a guide to set acceptance criteria for impact resistance. In addition, standard Navy interior topcoat paint, Coating Y, Formula Number 124, DOD-E-24607 [10] (Enamel, Interior, Nonflaming (Dry), Chlorinated Alkyd Resin, Semigloss), was evaluated in many tests to establish baseline data. A summary of acceptance criteria for small scale screening tests is given in Table 2.

SMALL SCALE SCREENING TESTS ON STEEL SUBSTRATE

0.25 in. (6.35 mm) thick mild steel was selected as the substrate for use in the small scale screening tests for selected coatings. Steel was selected so that the coatings themselves, without any additional combustion of the substrate, could be evaluated initially. The screening tests consisted of the areal density, adhesion, and impact resistance tests to evaluate coating weight and the effects of wear, tear, and rigors of long term shipboard deployment; flame spread, smoke generation, and Cone Calorimeter heat release rate to determine the combustibility of coatings for interior applications; and Modified UL-1709 fire resistance test using $2 \times 2'$ (60.96×260.96 cm) panels to determine the backside temperatures. A summary of test results is presented in Table 3.

Table 2. Acceptance criteria for small scale screening tests.

Test	Acceptance Criteria			Source
Areal density	Maximum areal density of 1.02 lbs/ft^2 (4.98 kg/m^2)			Draft MIL-PRF-XX 381[1]
Adhesion test ASTM D 4541 pull-off test [21]	270 psi (18.98 kg/cm^2)			Equal to or better than 50 mils (1.27 mm) of coating G*
Knife test MIL-PRF 24596 [22]	Difficult to furrow; No flaking or chipping			MIL-PRF 24596 [22]
Impact Tests ASTM D2794 [16]	50 in. lb (57.61 cm kg)			Performance equivalent or better than coatings G and H.
Flame spread ASTM E 162[13]	Not greater than 25			Draft MIL-PRF-XX 381 [1]
Smoke generation ASTM E 662[14]	Not greater than 200			MIL-STD 2031 [12]
Heat release rate, (kW/m^2) ASTM E 1354[15]	Heat flux (kW/m^2)	Peak	Average 300 s	MIL-STD 2031 [12]
	25	50	50	
	50	65	50	
	75	100	100	
Ignitability (s)ASTM E 1354	Heat flux (kW/m^2)	Time to Ignition, Minimum		MIL-STD 2031 [12]
	25	300		
	50	150		
	75	90		
Modified UL-1709 fire resistance test	Duration: 30 min; unexposed average temperature rise: 139°C			Draft MIL-PRF-XX 381 [1]

* = Coating G is NAVSEA approved coating for submarine application.

Table 3. *Summary of screening tests on steel substrate.*

Coating	Thickness (mils)	Areal Density (lbs/Ft^2)	Adhesion (psi) ASTM D 4541	Impact (in. lbs) ASTM D 2794	Flame Spread Index ASTM E 162	Smoke Density (D_m) (NonFlaming/ Flaming) ASTM E 662	Peak Heat Release Rate (kW/m^2) At 25/50/75 kW/m^2 heat flux ASTM E 1354	Modified UL-1709 Average Back Side Temp. at 30 min. (°F)	Modified UL-1709; Failure time Min : s	Modified UL 1709 Fire Resistance Test Comments
A	50	0.36	1922	>80	2	33/38	3/7/7	798	02:20	Char Layer does not bond to the panel
E	55	0.37	1605	>80	4	151/151	5/3/6	504	05:00	Expands well, some cracks in middle
F	200	1.05	312	>80	57	160/164	38/101/57	512	13:20	Some expansion, Some burning noticed
G50	50	0.41	270	50	4	115/139	6/32/62	880	02:40	Good char layer, adheres well
G10	10	0.082	1524	60	3	113/140	5/8/36	1032	02:00	Little intumescence, paint separated in center
H50	50	0.36	3184	60	8	245/440	21/96/105	779	01:00	Some expansion in center, bare steel on sides
H10	10	0.071	2376	60	2	112/210	20/72/84	962	02:20	Some expansion in center, bare steel on sides
I30	30	NA (1)	NA	NA	NA	NA	NA	596	05:40	Expands rapidly with good adhesion, little smoke
I50	50	0.37	885	30	2	50/50	6/5/23	462	11:20	Good char formation, some cracks near bottom
J	195	1.08	>1000	>80	14	188/348	37/138/165	445	11:20	Little intumescence, good adhesion to the panel
K	50	0.31	>1000	40	1	34/120	6/77/102	1324	01:20	Char layer does not adhere to steel, fell off
L	50	0.29	>1000	>80	2	62/80	10/7/12	1216	03:20	Very little intumescence, chunks of char fell off
N	50	0.35	1891	>80	3	101/280	57/57/105	787	02:00	Large section of char peeled away, test terminated
O	50	0.38	1870	>80	3	66/120	8/21/43	774	02:40	Coating expands and adheres to the substrate
P	1000	1.63	NA (2)	Bounces	71	336/256	63/93/138	1306	12:00	Lots of smoke initially, flaming chunks fell off
Q	62.5	0.27	>1000	>80	5	246/366	8/95/123	1292	02:40	Char layer did not adhere, steel exposed in places
Q^2	62.5	0.5	436	>80	3	223/402	44/100/153	1273	02:40	Coating peeled away from panel in sections
R	1000	1.96	NA (3)	60	7	79/133	NA (4)	NA	NA	Large chunks fell off during handling prior to test
Y	10	NA (5)	NA	NA	7	76/95	10/49/63	NA	NA	Standard navy nonintumescent interior paint.
Steel (B)	0	NA	NA	NA	NA	NA	NA	1342	<1:00	Steel glowing red on the back side, buckling.
SG	1.25 in	0.9–1.0	NA	NA	6	18/15	8/13/20	286	30:00	Standard StructoGard performed very well

NA = Not available; (1) Coating I–30 was tested only in the modified UL 1709 fire resistance test; (2) The piston could not be fastened securely to the surface to prevent air escape; (3) The piston broke through coating surface upon tightening; (4) Coating broke apart upon insertion into test frame; (5) Tests not conducted on control paint.

Physical Tests

Most of the screening test methods are standard test methods and are described in detail in references cited. The test results are shown in Table 3. The maximum areal density for Type I (High temperature insulation panel, fire protective) material under Draft MIL-PRF-XX 381 [1] is 1.02 lb/ft^2 (4.98 kg/m^2). Coatings F, J, P and R failed this screening test at manufacturer's recommended thickness.

Coating G is currently approved by NAVSEA for use as fire protective intumescent coating on antisweat PVC nitrile rubber hull insulation at a thickness of 10 mils (0.254 mm). Since coatings in this study are being evaluated as passive fire protection systems in this study, coating G was also tested at a thickness of 50 mils (1.27 mm). This coating exhibited far less adhesion strength at a thickness of 50 mils (1.27 mm). In order to consider the greatest number of coatings, the Pull-off Adhesion strength for G50 (270 psi, 18.98 kg/cm^2) was considered as the minimum acceptable value for this test. Most of the coating candidates met the goal of pull off strength greater than 270 lb/in.^{2} (18.98 kg/cm^2). Results could not be generated for foam candidates P and R. Candidate P had characteristics of a tough sponge while candidate R was a brittle foam.

The ASTM D 2794 Impact Test [16] involves dropping a standard weight onto a 0.5-in. (1.27 cm) diameter punch that deforms the coating and substrate. By gradually increasing the distance of the weight drops, the point at which coating failure occurs (e.g. cracking) is determined. Testing conducted on control coatings G and H produced impact results of at least 50 in. lbs (57.61 cm kg). This value corresponds to dropping a two-pound weight from a height of twenty-five inches. This value was adopted as the acceptance criteria. The ten systems which demonstrated acceptable performance are A, E, F, J, L, N, O, P, Q, Q2, and R. Coating G demonstrates better impact performance at 10 mils (0.254 mm) than 50 mils (1.27 mm). This is consistent with the soft cure of this paint at the higher thickness. Coating systems K is brittle. This feature causes the coating to crack under conditions of the impact test. Coating system I50 appears to have cracked due to poor compatibility with the primer.

Fire Tests

A flame spread index of 25 or less (ASTM E 162) was selected as the acceptance criteria for the small scale screening test based upon Draft MIL-PRF-XX 381 [1] which requires flame spread index of 25 or less in large scale ASTM E 84 test. This is the maximum value according to this standard for a material to be classified as a Type 1 PFP insulation material. In most cases, after the initial burn and flame spread, the coating underwent the intumescence process and the thickness and integrity of the intumesced char in general prevented further flame spread downward. Most coatings on steel substrate showed flame spread index values of less than 10. Coatings F and P failed this test and burned extremely fast. These two coatings have flame spread index values of 57 and 71 respectively.

The ASTM E662 test method was used to examine the specific optical density (smoke generation) produced by materials in the flaming and nonflaming test conditions. The acceptance criteria for this screening test was a maximum specific optical density of 200 or less. This criterion was selected from MIL-STD-2031 [12], which applies to the use of composite materials in submarines. The seven candidates which did not meet the acceptance criteria for smoke generation are: H10, H50, J, N, P, Q, and Q2.

Acceptance criteria for the cone calorimeter heat release rates and time to ignition were selected from MIL-STD-2031 [12]. Acceptance criteria for time to ignition at 25, 50, and 75 kW/m^2 heat flux were set at 300, 150, and 90 s respectively. Acceptance criteria for peak heat release rate at 25, 50, and 75 kW/m^2 heat flux was set at 50, 65, and 100 kW/m^2 respectively. Acceptance criteria for average heat release rate (300 s) at 25, 50, and 75 kW/m^2 heat flux was set at 50, 50, and 100 kW/m^2 respectively. On the steel substrate, coatings A, G10, L, and O passed all the requirements set forth in the acceptance criteria at all three heat fluxes. Coatings E, and I50 passed all the requirements of acceptance criteria at heat fluxes of 25, and 50 kW/m^2, but failed the requirements of time to ignition at 75 kW/m^2.

Modified UL-1709 Fire Resistance Tests

For the purposes of evaluating intumescent coatings as stand alone replacement for currently used fire insulation, this is the most meaningful small scale screening test. In this test, a 0.6 m (2 ft.) square specimen in the vertical orientation (bulkhead) is placed in front of a 147 kW propane jet burner that produces temperatures of 2000°F (1093°C) at the specimen surface. This fire resistance test generates heat flux of 180 kW/m^2 at the exposed surface. These heat fluxes correspond to those produced by a hydrocarbon pool fire and the fire curve in the UL-1709 [2] fire resistance test. In accordance with Draft MIL-PRF-XX 381 [1], the pass/fail criteria for a 30 min rating is backside peak temperature rise less than 180°C, and more critically, average backside temperature rise less than 139°C using UL-1709 fire curve which simulates a post flashover fire. The results from this test can be used to compare material performance in containing and preventing the spread of fire, smoke, and fire gases between compartments or spaces. Due to direct flame impingement from the burner on the exposed surface, this test is capable of discriminating between coatings that produce soft or fragile char during heating. The Modified UL-1709 fire resistance test apparatus is shown in Figure 1. The average far side temperatures obtained during these tests for all selected coatings on steel substrate are shown in Figure 2.

None of the coatings, tested at manufacturer's recommended coating thickness, met the acceptance criteria of average backside temperature rise less than 139°C. StructoGard passed the acceptance criteria. Bare steel recorded backside temperatures of 1342°F (727.8°C). Because of this, coatings which exceeded backside temperatures of 1000°F (537.8°C) were eliminated at the conclusion of steel substrate screening tests. These coatings included G10, K, L, P, Q, and Q2. Coating N also performed poorly. Large sections of the char fell off coating N during the test, and the test was terminated after approximately 10 min. Coating R was not tested in the Modified UL-1709 Fire Resistance test because the coating crumbled while being loaded into the test frame. A subsequent panel was not prepared as this behavior and cure time were considered inappropriate for naval applications. The most common failure mode observed during Modified UL-1709 fire resistance tests was the poor substrate adherence of the intumescent coatings and the fragility of the intumesced char which resulted in the falling off of large chunks of intumescent coatings during these fire tests. An example of this behavior is shown in Figure 3.

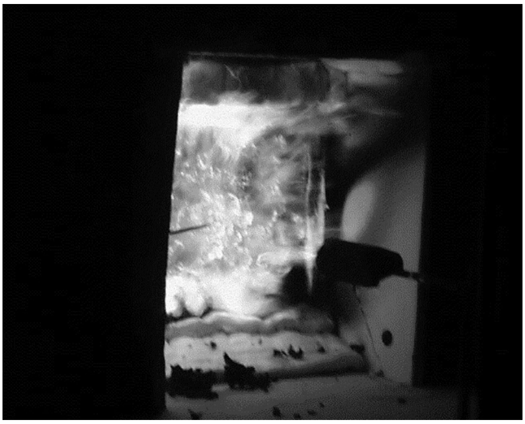

Figure 1. Modified UL-1709 fire resistance test apparatus.

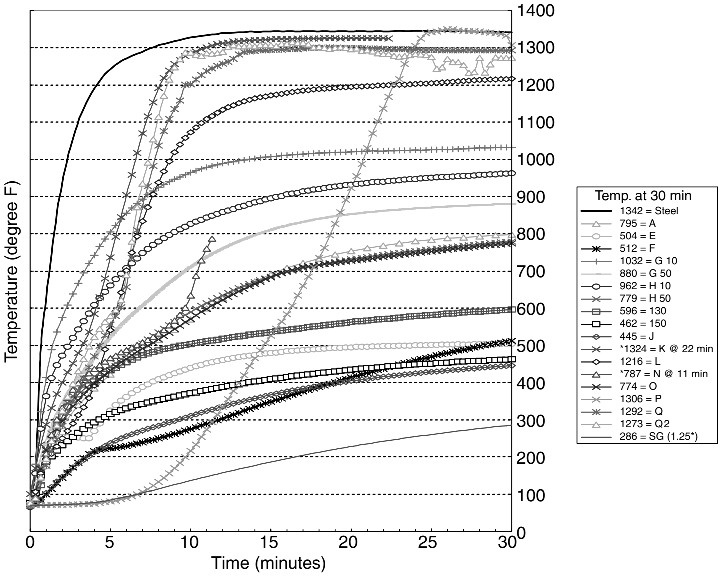

Figure 2. *Backside average temperatures during modified UL-1709 fire resistance tests with steel substrate.*

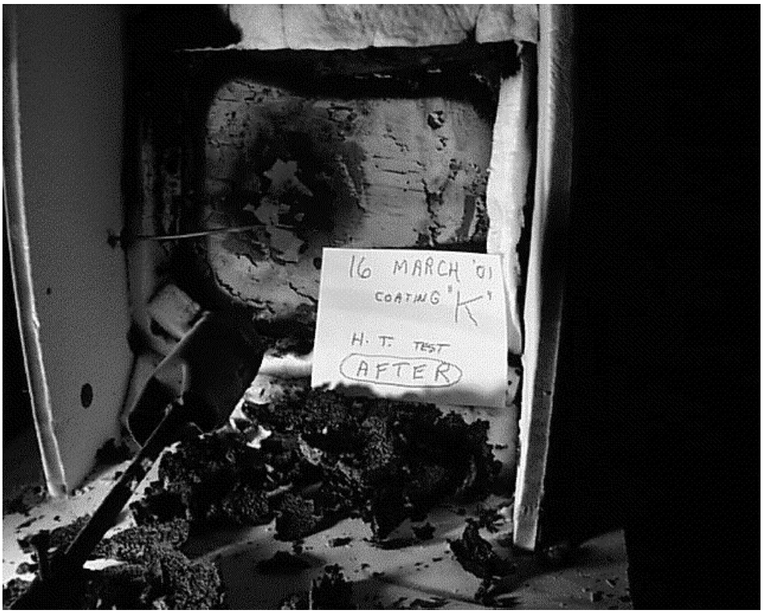

Figure 3. *Coating K in the modified UL 1709 test with char pieces that fell off.*

Several of the coatings demonstrated varying degree of ability to slow heat transfer through the steel panel. Coatings E, F, I50, and J had average backside temperatures under 525°F (273.9°C) after 30 min. Coating I was tested at both 30 mils (0.76 mm) and 50 mils (1.27 mm). The additional 20 mils added to the panel reduced the final average backside temperature by 134°F (74.4°C).

Down-selection of Coatings

Extensive data generated from screening tests on steel substrate is summarized in Table 3. These small scale screening tests resulted in the selection of six coatings. The six down selected coatings are: A, E, G50, I50, J, and O. These six coatings were further evaluated using StructoGard and GRP as substrates.

Small Scale Screening Tests on StructoGard® Substrate

StructoGard is currently approved for use onboard ships as a passive fire protection system in accordance with Draft MIL-PRF-XX 381 [1]. Typically, once the insulation is installed onboard ship, an interior chlorinated alkyd topcoat paint F-124 [10] would be applied to the insulation at a thickness of 10 mils (0.254 mm).

StructoGard was chosen as a test substrate to determine the benefits of replacing standard interior topcoat paint (F-124) on fire insulation with fire resistant intumescent coatings. In addition, an investigation was made to determine how these coatings perform if they were used as an add-on with StructoGard in order to reduce the overall thickness of the StructoGard required to meet Navy fire resistance requirements in accordance with Draft MIL-PRF-XX 381. To answer this question, half the standard thickness of StructoGard, 0.625 in. (1.59 cm.) was used as a substrate in conjunction with 50 mils (1.27 mm) of intumescent coating A.

Commercially available Navy standard StructoGard was also tested to provide control data. The coatings, which were down-selected from the steel substrate screening process (A, E, G, I, and O) were applied to 1.25 in. (31.75 mm) StructoGard samples without a primer to a thickness of approximately 10 mils (0.25 mm). Coating J was not used for this study because it is a mastic type coating and is not suitable for paint application to StructoGard. All of the StructoGard substrate testing was conducted without a steel panel behind the insulation with the exception of the Modified UL-1709 fire resistance test. A $2' \times 2'$ (60.96×60.96 cm) steel panel was placed behind the insulation for all fire resistance testing. The test results are shown in Table 4.

Table 4. Summary of screening test results on StructoGard substrate.

Coatings	DFT mils	Flame Spread Index ASTM E 162	Smoke Density Dm (NonFlaming/Flaming) ASTM E 662	Peak Heat Release Rate (kW/m^2) at 25/50/75 kW/m^2 Heat Flux ASTM E 1354	Modified UL- 1709 Fire Resistance Avg. Backside Temp. after 30 min (°F)	Modified UL 1709 Test Comments
1.25″ SG (1)	NA	6	18/15	8/13/20	295	Unpainted control
1.25″SG + A	10–15	11	32/36	7/55/119	304	Large pieces of coating sagged and came off.
1.25″ SG+E	10–15	30	85/79	56/87/139	320	The coating adhered during the test.
1.25″ SG + G	10–15	19	151/186	31/77/139	287	Some fissures formed but the coating did not fall off.
1.25″SG + I	10–15	9	73/96	5/81/135	320	Adhesion to SG substrate was poor.
1.25″SG + O	10–15	19	118/150	25/81/124	375	Some coating came off during the tests.
1.25″SG + Y	10–15	29	134/92	43/121/180	328	Paint peeled off during the fire resistance test.
5/8″SG	NA	NA	NA	NA	550	Does not meet the acceptance criteria for fire resistance test.
5/8″SG + 50 mils A	50	NA	NA	NA	315	The char survived the test intact, but was only held up by the test frame. It was not bonded to the SG.

(1) StructoGard is currently used at the thickness of 1.25 in. (3.18 cm) in U.S. Navy ships.

The flame spread index of StructoGard itself has the value of 6. However, the flame spread index of StructoGard with standard interior topcoat paint F-124 (coating Y) is 29. With the exception of coating E which had an index of 30, all other coatings fall within the acceptance criteria (25 or less) and demonstrate performance which is better than the currently used topcoat. It should be noted here that the intumescent coating thickness applied on steel substrate was about 50 mils (1.27 mm) whereas the intumescent coating thickness applied on StructoGard substrate is about 10 mils (0.25 mm) simulating the thickness if it were used as a topcoat paint. The flame spread index values for the intumescent coatings (10 mils, 0.25 mm) on StructoGard substrate are much higher than the same coatings (50 mils, 1.27 mm) applied to bare steel. The glass fiber insulation does not conduct heat like the steel plate. This results in higher temperatures at the interface between the coating and the StructoGard substrate which accounts for higher flame spread index values when compared with the steel substrate.

In ASTM E 662 smoke generation tests, all of the intumescent coatings applied on StructoGard met the acceptance criteria of 200 or less for maximum specific optical density (Dm) in both flaming and non flaming modes. None of the candidates, however, performed better than unpainted StructoGard.

In cone calorimeter testing (ASTM E 1354), only the unpainted StructoGard met the acceptance criteria for peak heat release rates at all three heat fluxes. All coatings applied over StructoGard substrate, including the Navy standard interior paint F-124, failed to meet the peak heat release rate acceptance criteria at all three heat fluxes of 25, 50 and 75 kW/m^2. However, the combustion of most coatings was only for a short duration at all three heat fluxes.

Modified $2' \times 2'$ UL-1709 Fire Resistance Tests With StructoGard Substrate

A total of nine Modified UL-1709 Fire Resistance tests were conducted with StructoGard insulation. Three control samples were tested in the Modified UL-1709 Fire Resistance Test; 0.625 in. (1.59 cm) thick StructoGard; 1.25 in. (3.18 cm) thick StructoGard; and 1.25 in. (3.18 cm) thick StructoGard with Navy standard interior paint F-124 (coating Y) at a thickness of 10 mils (0.25 mm). Coatings A, E, G, I, and O were tested at a thickness of 10–15 mils on 1.25 in. (3.18 cm) thick StructoGard substrate. In addition, a 0.625 in. (1.59 cm) thick StructoGard sample with 50 mils (1.27 mm) of coating A was also tested. The test results are shown in Figure 4.

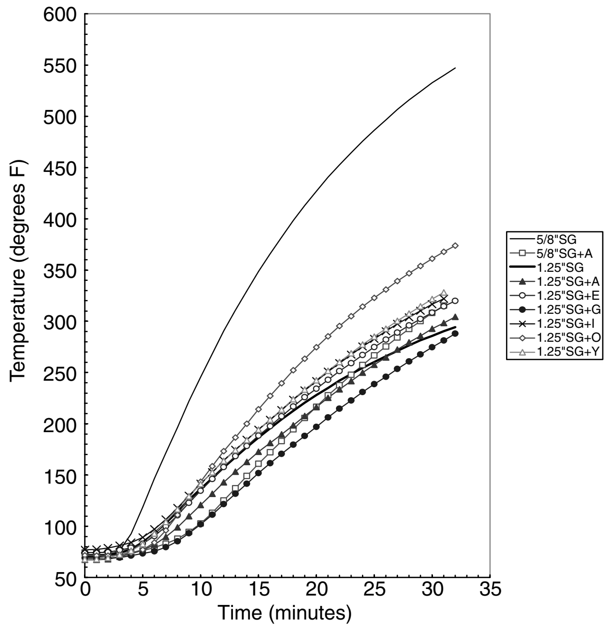

Figure 4. Modified UL-1709 fire resistance test results for StructoGard substrate.

The acceptance criteria for modified UL-1709 fire resistance screening test was set at average backside temperature rise after 30 min not to exceed 139°C. Assuming ambient temperature of 25°C, test specimen with average backside temperatures after 30 min of 164°C (327°F) or less are considered to have passed this test. Unpainted StructoGard at 1.25 in. (3.18 cm) and 5/8 in. (1.59 cm) thickness had average backside temperatures after 30 min of approximately 295°F (146.1°C) and 550°F (287.8°C) respectively. StructoGard at a thickness of 5/8 in. (1.59 cm) with 50 mils (1.27 mm) of coating A had an average backside temperature of 315°F (157°C) after 30 minutes. Therefore, it meets the average temperature rise criteria for this test. Areal density of 50 mils (1.27 mm) thick coating A by itself is about 0.36 lbs/ft^2 (1.76 kg/m^2). Areal density of 5/8 in. (1.59 cm) StructoGard is about 0.5 lbs/ft^2 (2.44 kg/m^2). Thus at comparable fire resistance performance, 5/8 in. (1.59 cm) StructoGard with 50 mils (1.27 mm) of Coating A weighs 0.86 lbs/ft^2 (4.20 kg/m^2) versus 1.0 lbs/ft^2 (4.88 kg/m^2) for 1.25 in. (31.75 mm) StructoGard. This represents a weight saving of 14% at significant additional material and installation cost.

The most common observation made during Modified UL-1709 fire resistance tests with StructoGard substrate was the poor adherence of the intumescent coatings and the fragility of the intumesced char which exhibited propensity for falling off from the substrate in large chunks during these fire tests.

Small Scale Screening Tests of Coatings on GRP

In order to assist in the final selection of coatings for testing in intermediate Room Corner Fire Tests, all six down selected intumescent coatings from the steel substrate screening process were also tested on a 3.5″ (8.89 cm) thick balsa wood core sandwich composite substrate. The sandwich composite consisted of 0.25″ (0.635 cm) thick glass reinforced vinyl ester resin (Derakane 510A) skins and 3.0 in. (7.62 cm) thick balsa wood core. The coatings included A, E, G50, I50, J, and O. All coatings were applied at manufacturer's recommended thickness. Coatings A, E, G50, and I50 were applied at 50 mils (1.27 mm) thickness, and J was applied at 195 mils thickness. The GRP surface was wiped clean prior to coating application. All coatings were applied with the primer at the thickness utilized for the steel substrate screening tests. Table 5 summarizes the test results for the coatings with GRP (sandwich composite) substrate.

The GRP evaluated under this program is a thick sandwich structure. The important fire issues with GRP are the flammability or combustibility of the GRP substrate, potential for the high smoke generation, and flashover. Fire resistance, as measured by the backside temperatures, is not the main issue. GRP sandwich structure is inherently insulative and prevents high backside temperatures due to its large thickness when tested in Modified UL 1709 fire resistance tests.

In ASTM E 162 flame spread index tests, all coatings meet the acceptance criteria of 25 or less including the bare GRP. The flame spread index of bare GRP itself is 24. In ASTM E 662 smoke generation tests, the Navy standard GRP produces very dense smoke and fails the acceptance criteria. In nonflaming and flaming modes, the maximum specific optical density for bare GRP is over 600 and 900 respectively. When bare GRP was applied with six selected coating candidates, the four candidates which pass the acceptance criteria (Dm less than 200) are A, E, G50, and I50. In ASTM E 1354 cone calorimeter testing, all six coatings protect the GRP substrate at 25 kW/m^2 and pass MIL-STD-2031 requirement by preventing ignition of the underlying substrate. At 50 kW/m^2, only coatings A and I prevent ignition of the composite substrate. At 75 kW/m^2, the only coating which meets the peak heat release rate criteria is coating I. Although ignition occurs, the peak heat release rate does not exceed 100 kW/m^2.

Table 5. Summary of screening test results on GRP substrate (sandwich composite).

Coating ID	DFT Mils	Flame Spread Index ASTM E 162	Smoke Density (D_m) (NonFlaming/ Flaming) ASTM E 662	Peak Heat Release Rate (kW/m^2) at 25/50/75 kW/m^2 Heat Flux ASTM E 1354	Modified UL-1709 Fire Resistance Avg. Backside Temp. after 30 min (°F)	Modified UL 1709 Test Comments
GRP (1)	NA	24	635/904	135/238/342	<170	GRP face flaming and smoking.
GRP + A	50	5	35/42	7/13/115	<130	Pieces of coating fell off during the test. GRP face burning. Test terminated early
GRP + E	50	4	186/190	8/69/131	<150	Severe flaming on the edge during the test.
GRP + G	50	24	142/152	2/78/145	<90	The test terminated after 7 min due to severe cracks in the coating and GRP involvement.
GRP + I	50	1	72/99	0/15/85	<160	Some burning of GRP at the edges.
GRP + J	195	10	223/303	7/135/201	<150	Black smoke and heavy flames during the test. Coating adherence to the substrate was excellent.
GRP + O	50	2	171/640	21/158/237	<90	Severe cracking of the coating during the test. Test terminated early.

(1): 3.5 in. (8.89 cm) thick GRP; 0.25 in. (6.35 mm) thick glass/vinyl ester skins with 3.0 in. (7.62 cm) thick balsa wood core.

A total of seven modified UL-1709 Fire Resistance Tests were conducted on the GRP substrate. These included the six fire protective coatings and a bare composite sample. Because of the thickness (3.5 in., 8.89 cm) of the composite material, the heat transfer through the panels was greatly reduced as evidenced by average backside temperatures after 30 min of less than 200°F (93.3°C). Even though the material passes the fire resistance tests, the GRP substrate burned and produced dense smoke. The test on coating G50 was terminated early (7 min) because the coating began to significantly crack and the underlying GRP was becoming significantly involved in the fire. The test on coating A was also terminated early (20 min) due to significant involvement of the underlying composite substrate which resulted in very dense smoke.

Except for the coating J, the most common failure mode observed during Modified UL-1709 fire resistance tests was the poor substrate adherence of the intumescent coatings and the fragility of the intumesced char which resulted in the falling off of large chunks of intumescent coating during these fire tests.

INTERMEDIATE ROOM CORNER FIRE TESTS

Prior to beginning the corner fire tests, candidates were further down-selected on the basis of their performance in small scale screening tests on all three substrates, namely, steel, StructoGard, and GRP. Coatings A, E, and I were selected for room corner fire tests. Coatings G, J and O were eliminated from further consideration. Coating G was eliminated for several reasons. At 50 mils (1.27 mm), the coating is soft and pliable. At a thickness of 10 mils (0.254 mm) on steel substrate, the coating came off at the center of the panel during modified UL-1709 fire resistance test. In the Modified UL-1709 fire resistance test, coating G on the GRP substrate did not last more than 7 min. The coating displayed some cracking. As a result the GRP substrate was exposed to the heat and generated heavy smoke, and the test was stopped prematurely. Coating J was eliminated because at 195 mils (4.95 mm) thick, it failed the acceptance criteria for areal density. Furthermore, even at this thickness on steel substrate, it failed the Modified UL-1709 fire resistance test in less than 12 min. With both steel and GRP substrates, some big flames and heavy smoke were generated in the first few minutes during the Modified UL-1709 fire resistance test. The coating J consistently failed the smoke density test in flaming mode with both steel (Dm = 348) and GRP (Dm = 303) substrates. Due to smoke and heat generation of coating by itself, this candidate is not suitable for use in shipboard interior applications. Coating O was eliminated because the char of coating O seemed to burn off resulting in break down of thermal protection of the substrate within 10 min. The Modified UL-1709 fire resistance test was stopped after 10 min because of the cracking of coating and exposure of GRP substrate.

Modified Room Corner Fire Tests

Coating candidates A, E, and I were further tested in the room corner configuration. For comparison purposes, steel corner protected with 1.25″ (31.75 mm) StructoGard was also tested. In this study, an open steel corner (two sides and the ceiling) was constructed and used instead of a full scale ISO 9705 [8] room. The 4×8 ft (121.92×243.84 cm) open steel corner was subjected to the ISO 9705 fire curve (100 kW for first 10 min, 300 kW for the last 10 min). The open corner consisted of five 4×4 ft (121.92×121.92 cm) steel panels which were bolted to a steel frame. The panels were primed and coated to a thickness of 50 mils (1.27 mm) prior to installation in the corner test assembly. After all panels were installed, a final skim coat of paint was applied to create a smooth transition from one panel to the next. The dry film thickness of this skim coat averaged approximately 2–3 mils. The tests were conducted underneath the exhaust hood. Data was collected on the flame spread, heat release, gas species production and smoke production rates as well as surface and backside temperatures. The ability of coatings to adhere during the fire tests was also evaluated qualitatively.

No acceptance criteria were established in this study for corner fire tests. Not enough data exists for the use of intumescent coatings as passive fire protection system in shipboard environments for steel structures. The High Speed Craft (HSC) code [17] for GRP structures does have acceptance criteria for room corner fire tests which have been adopted by the U.S. Navy [18]. This acceptance criteria for GRP structures are: Peak heat release rate (excluding source) less than 500 kW; Average heat release rate for test (excluding source) less than 100 kW; Flame spread must not reach 0.5 m above the floor; Peak smoke production rate less than 8.3 m^2/s; and test Average smoke production rate less than 1.4 m^2/s.

Coating E applied on the steel corner during 300 kW fire exposure is shown in Figure 5. All coatings meet the heat release and smoke production rate acceptance criteria established for GRP (combustible) structures [18]. The heat release rates for the intumescent coatings observed in these tests are very low. The net peak heat release rate for all coatings was less than 100 kW. This suggests that intumescent

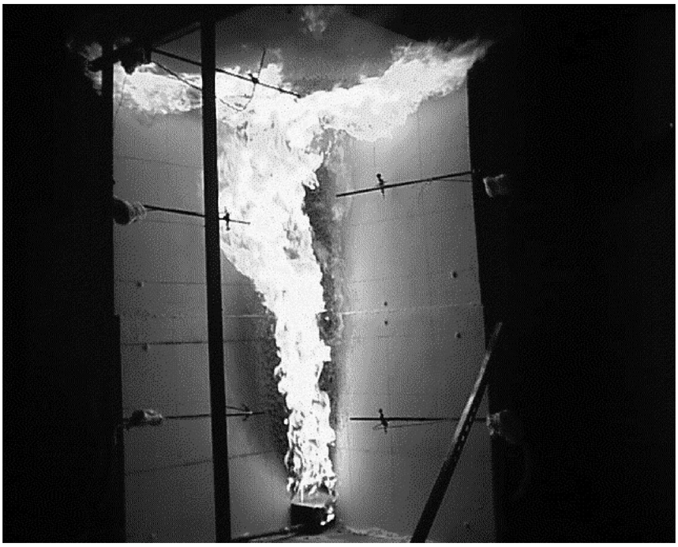

Figure 5. Coating E with steel corner during 300 kW fire exposure test.

coatings (A, E, or I) will not, by themselves, cause a flashover when applied at 50 mils (1.27 mm) or less on steel substrate.

Some char was observed to have fallen off from the ceiling during all corner tests. Some visible flaming of coating A was observed during the test directly in the corner. However, no visible flame spread was observed during the test for coating A. The post fire inspection of the corner for coating A revealed that large fissures were present in the coating surface. Also, along the overhead on the right hand side in the corner was a very large loose piece of char. Several holes were also noticed in the char layer in this area. For coating E, some visible flaming of the coating was observed during the test in the area around the vertical corner. The flame spread was limited to less than 6 in. (15.24 cm) beyond the fire plume in the vertical corner. Some very small pieces of char fell during the test. Coating E produced the highest peak smoke production rate. Coating I demonstrated very poor adhesion to the overhead panel during the 300 kW portion of the fire test. In two instances, large sections of the overhead char layer fell from the panel. There was some combustion of the coating in the area right near the burner. The StructoGard corner initially produced noticeable smoke during the 100 kW portion of the test. This was due to the heating of the adhesive. However, visible combustion of this mastic adhesive was not observed, although small increases in the heat release rate are present at the onset of the fire and when the fire size was increased. Once the adhesive in the area around the fire plume had burned away, most of the smoke ceased. When the fire size was increased to 300 kW a much smaller spike in the smoke production rate occurred. There was very little net heat release observed during this test. Coatings E and I both had similar backside temperature rise profiles and demonstrated superior heat transfer protection than coating A during the testing. However, the char adhesion of coating I was inferior to both coatings A and E. All three coatings were recommended for large scale testing in ex-USS Shadwell (U.S. Navy research ship) by NRL.

FULL SCALE FIRE TESTS IN EX-USS SHADWELL

Large-scale experimentation was conducted in compartment 3-81-2 aboard the ex-USS SHADWELL [19]. All intumescent and baseline coatings were applied to both sides of a 6.1 m (20 ft) long, steel bulkhead separating the fire compartment from an instrumented boundary compartment. A complete description of the test spaces has been previously given [20]. Application procedures for all coatings were in strict compliance with manufacturer recommendations and in accordance with appropriate work practices. A view of the test ready bulkhead, seen on the left from the fire compartment side, is shown in Figure 6.

Figure 6. View of test bulkhead and insulated, nontest surfaces.

All fire compartment surfaces, except the deck and test bulkhead itself, were permanently covered with 1.25" (31.75 mm) thick, Navy fire insulation StructoGard FB. This layer of insulation insured the test bulkhead was exposed to the maximum insult possible. The insulation also served to prevent wide spread, heat related damage to the nontest surfaces of the fire compartment. To insure sufficient air was available for maximum burning efficiency and maximum sustained burning temperatures, the forward and after archways of the fire compartment remained open during execution of all fire testing.

Three test insults were generated to evaluate performance of test coatings against the draft MIL-PRF-XX 381 performance criteria. The radiant and wood crib (incipient) tests were performed to expose all bulkhead treatments to the widest range of potential fire threats possible. A pair of propane fueled, exposed element, resistance heaters produced a measured, nonflaming, radiant insult of 5–8 kW/m^2. The growing, incipient fire, fueled by two wood cribs constructed of kiln dried, red oak, generated an insult computed to be 1.5 MW. A hydrocarbon fueled spray fire, n-heptane pressurized to 40 psi (2.81 kg/cm^2) and released through a pair of BETE Model FF052, extra-wide angle nozzles generated an insult computed at 2 MW. Test duration was 30 min.

It was decided that no hose stream tests would be performed during the large scale series. The results from intermediate scale tests have shown that intumescent chars may be incapable of withstanding mechanical shear forces. Hose stream tests are some times performed at the end of standard full scale tests to simulate the firefighting operation and investigate the fire integrity of the test specimen. The absence of pressurized streams of water insured that post test documentation of all coatings would accurately represent damage due to flame turbulence and thermal degradation only.

All coating combinations evaluated in the full scale fire resistance tests (Ex-USS SHADWELL) failed the draft MIL-PRF-XX 381 acceptance criteria for average and peak far side temperature rise of 139, and 180°C respectively. This is shown in Figures 7 and 8.

Because of the limiting temperature rise criteria outlined in draft MIL-PRF-XX 381, any material selected for its passive fire protection (PFP) qualities should be capable of protecting the nonfire side surface of any treated bulkhead or overhead. More specifically, any coating identified as having PFP qualities which is applied to any surface aboard ship, must be capable of withstanding the rigors of a fire and be capable of mitigating temperature rise within or across the component being coated. None of the subject intumescent coatings showed the ability to do this during large scale fire testing.

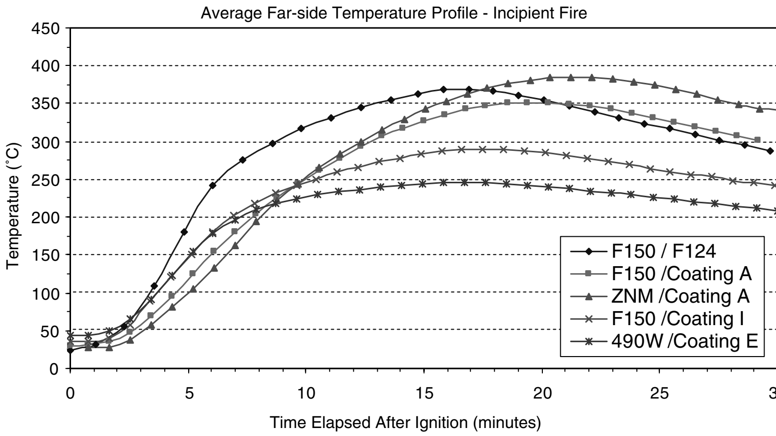

Figure 7. *Performance of test coatings against a 1.5 mw wood crib.*

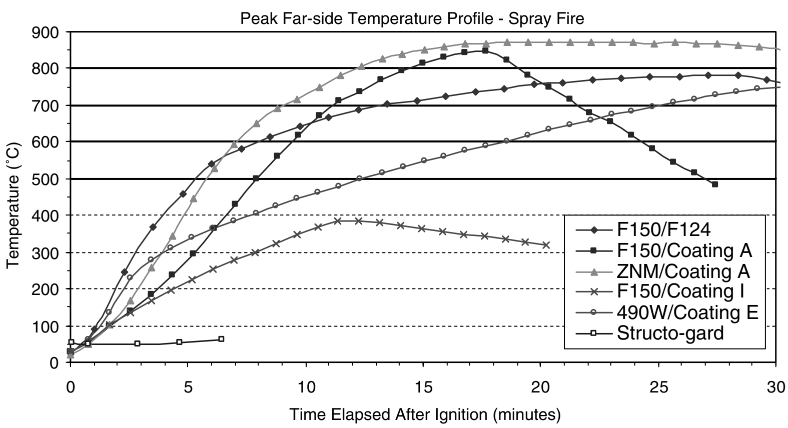

Figure 8. *Performance of test coatings and fire barrier insulation against a 2 mw heptane spray fire*

Figures 7 and 8 document the respective performance of the test coatings and fire barrier insulation combinations. All coatings were exposed to all three previously described thermal insults. The Navy fire barrier insulation, StructoGard FB, was exposed to the spray fire insult only because it was the most severe threat. The origin of the plots is average ambient temperature on the far side surface and time equals zero (the instant of ignition). The plots clearly show that all coating combinations were unable to keep the far side bulkhead surface from exceeding the critical, threshold temperature values.

The premature termination of tests evaluating coating A and the fire barrier insulation was due to technical problems with the spray fuel system. Coating A had failed the Draft MIL-PRF-XX 381 criteria prior to termination of the test so the brevity of this experiment is irrelevant. Due to premature test no definitive conclusion can be made regarding its 30 minute performance.

No test coating was capable of forming a char layer on the nonfire side of the bulkhead. Test coatings on the nonfire side smoldered, cracked, peeled and delaminated. Test coatings E and I formed char layers on the fire side of the test bulkhead. The char layers formed by exposure to the incipient (wood crib) fire tended to be extremely fragile, showed a propensity to crack during the fire and were highly variable in their thickness. Char layers formed by coatings E and I developed an armor like shell when exposed to the higher temperatures generated by the spray fire. The spray fire generated char layers were also highly variable in thickness and showed a tendency to crack. Test coating A delaminated from more than 90% of the bulkhead surface on both the fire and nonfire sides when exposed to both the incipient and spray fire insults.

Coatings E and I tended to be nonreactive when located low and at a distance from the seat for the test fires. Following the incipient and spray fire insults there were several areas of the intumescent paint coated, fire side, test bulkhead which had not produced a char layer. The condition of the coating in these areas was nearly pristine with the exception of some minor soot discoloration. Arbitrarily selected portions of these nonreacting intumescent coatings were exposed to direct, flame impingement from a propane torch. None of the reported intumescent coatings were able to produce a char layer, of any type or thickness, under this post test direct flame impingement. This demonstrates that baking of coatings, for a sufficient period of time, may cause the subject coatings to undergo some type of chemical change.

Test coating A was observed to support flaming combustion after the product delaminated and fell to the test compartment deck. Test coatings E and I exhibited characteristics of flaming combustion during the first 5–7 min of each test. The most likely reason for the short-term presence of the flaming is each coating evolved volatile vapors during generation of the char layer.

CONCLUSIONS

The objective of this program was to identify passive fire protection (PFP) coatings for shipboard interior applications capable of meeting

U.S. Navy (USN) fire resistance requirements of 30 min rating with backside average temperature rise less than 139°C using UL-1709 fire curve (post flashover fire). Several commercially available water and solvent based coatings were evaluated on steel, StructoGard, and GRP substrates. This evaluation consisted of small scale fire, adhesion, and impact tests; intermediate scale corner fire tests, and full scale fire tests conducted aboard ex-USS SHADWELL.

Based on the small, intermediate, and full scale fire tests conducted by the U.S. Navy in this study, it is concluded that water based intumescent coatings exhibited persistent problem of inconsistent adherence to the substrate, and fragility of char. All coatings failed the modified UL-1709 fire resistance and full scale fire tests at the manufacturer's recommended thickness. Time to failure was less than 15 min.

All solvent based coatings also failed the modified UL-1709 fire resistance test at manufacturer's recommended thickness. Even at a coating thickness which exceeded the areal density of StructoGard, such as Coating J, time to failure was less than 15 min. Also, solvent based intumescent coatings produce heavy smoke and may produce untenable conditions. They are only suitable for exterior applications.

Regarding the potential for the use of intumescent coatings as fire retardant paint in lieu of Navy standard interior paint F-124, the test results are mixed. Compared with chlorinated alkyd interior topcoat F-124, water based intumescent coating A produced less smoke and lower flame spread index on StructoGard substrate. However, it is not clear if water based intumescent coating can be used as interior topcoat by itself in shipboard environments due to questions regarding water, solvent, and hydraulic fluids resistance, long term substrate adherence, etc. Shipboard trial patches conducted with Coating A received negative feedback from the shipboard personnel. Complaints ranged from coating flaking, chipping, and easily getting dirty. Water based intumescent coatings may require additional top coat, at significant additional cost, before they can be used as a practical system for interior shipboard applications.

Based on small-scale modified UL-1709 fire resistance tests, it appears that 5/8 in. (1.59 cm) StructoGard with 50 mils (1.27 mm) of water based coating A has comparable performance to 1.25 in. (31.75 mm) StructoGard. The areal density of 50 mils (1.27 mm) thick intumescent coating A is 0.36 lbs/ft^2 (1.76 kg/cm^2). Thus, at comparable fire resistance performance, 5/8 in. (1.59 cm) StructoGard with 50 mils (1.27 mm) of Coating A weighs 0.86 lbs/ft^2 (4.2 kg/cm^2) versus 1.0 lbs/ft^2 (4.88 kg/cm^2) for 1.25 in. (31.75 mm) StructoGard. This represents a weight saving of 14% at significant additional material and installation cost.

Prior to wide acceptance of intumescent coatings for shipboard passive fire protection, other issues that must be explored include cost, performance and durability of coatings over a life time of use.

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